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Seminar paper

Simulation of Building Processes based on BIM

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Content

1 Introduction and motivation

At the moment, the importance of preliminary planning and outline planning is rising. Due to the possibility of simulating real world behaviour, more and more effort can be put into planning a process and a accordingly high detailed model to fulfil real world requirements is needed. Additionally process simulations make sense to support the construction progress schedule. There is the opportunity to optimize the use of resources and the building design. Based on these considerations, and taking spatial and temporal restrictions into account already in the construction progress schedule, unscheduled delays can be avoided.
To illustrate this concept, figure 1-1 shows an example of how different tasks of a construction process can be assigned to different project teams to build up the basis of a construction.

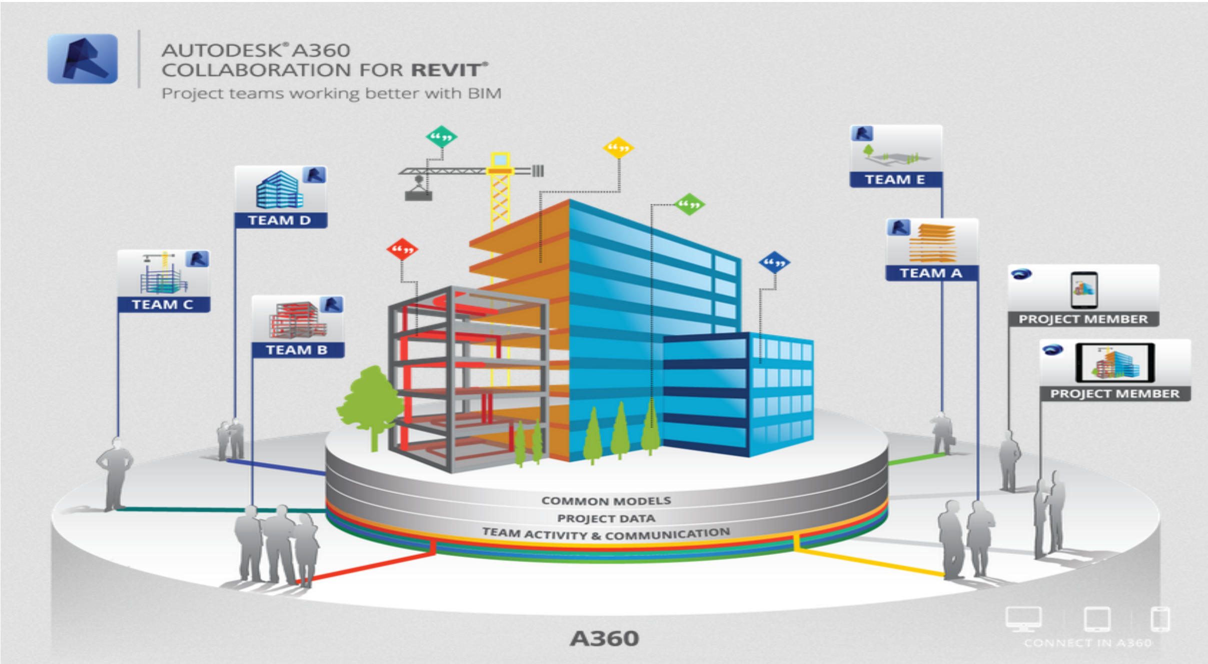


Abbildung 1-1: Autodesk Revit illustration for different teams working on process steps, from which the foundation of the building is made of [AUT16]

1.1 Problem definition

Architectural design, structure analysis and construction management are traditionally separate steps, whose cooperation is important in order to avoid accidents in the construction process. The intended merger can succeed through the integration of a Building Information Model(BIM) extended with an appropriate 4D-simulation, since the basic BIM is a static 3D model, which does not explicitly contain the time component. This is why this work will present what BIM actually is and why it is arresting so much attention nowadays. In addition to that, currently used simulation models will be presented, which show to what attention should be paid in the course of a process simulation and what the difficult steps of the implementation are.

1.2 Structure of this work

This work is divided into two greater parts. Firstly, the basis of today's construction process simulation or optimization will be presented. It will be shown up, what the term BIM stands for and in which fields it is already used.
Secondly, the concept of construction process simulation will be presented. Here, some general information and a short overview of the state of the art will be shown up, before the different existing models and the constraint based simulation will be explained. In the last step, there is a special focus on the temporal and spatial restrictions since they are often neglected, when generating the work schedule and they are probably the most difficult restrictions in the construction process.

2 Building Information Modelling (BIM)

In this chapter, the basis of the simulation, the so-called ‘Building Information Modelling’(BIM) will be presented. In this way, it will be emphasised what is already possible at the moment and on which approaches and basic considerations this work is building.

2.1 What is BIM and what is it used for today?

BIM is a methodology, which is necessary for the preparation, coordination and transfer of an interdisciplinary, object-oriented 3D-building model. It covers the whole life cycle of a building so that it supports the process from the first draft of the building until its demolition. With the integration accordingly high detailed components, one is able to do things like structural analysis and efficiency calculations already before the project breaks ground.
The first concept of BIM exists since the 1970s, but didn't become famous until 2002. Today, BIM is used for the continuous integration of building data, which are relevant for planning, execution and utilisation, in a central database [BEH15]. It is mainly used in the US, but starts spreading in all Europe. For example the adoption of BIM in the United Kingdom has increased from 13% in 2010 to 55% in 2015 [NBS16]. Germany is two or three years behind its neighbours (Netherlands or United Kingdom) in terms of adopting BIM. The first efforts came from the German minister for transport Alexander Dobrindt, who announced a "timetable for the introduction of mandatory BIM for German road and rail projects from the end of 2020"[TBH16].

Additionally, there are two different forms of BIM that are currently used.
'Big BIM' is defined as the interdisciplinary cooperation of all the partners, who are involved in the planning, the execution and the use, and their software tools by different manufacturers. So far, it has remained more or less a vision. Nevertheless, it is already practised in some segments, e.g. within the scope of design- and execution planning between structural engineers and home engineering planners.
Currently, 'Little BIM' is more widely spread in companies. This means the use of BIM as an isolated solution within a company or as a planning discipline and a software solution of a manufacturer. Nowadays, efficient interfaces are necessary for an interdisciplinary cooperation. This is because of an in Germany predominant collaborative planning and a fragmented heterogeneous corporate structure, which several offices with different software tools are working on the same project. Eventually, plenty of geometrical and alphanumeric information of different data formats are created through the process of conception, design, planning, building, use, management and dismantling of buildings [BEH15].

For the exchange of BIM data, Industry Foundation Classes (IFC) have established as a basis. The IFC description of architectural model is a set of specifications and data representation

standards developed by international alliance for interoperability(IAI). The goal of IFC is providing a system-independent possibility to describe all building data for their whole life cycle It supports data exchange, sharing and management and parametric represented objects. Everything needs to be converted to basic geometric entities in IFC form [HU08].
The following figure(2-1) shows an example for a part of a IFC file and the 3D model:

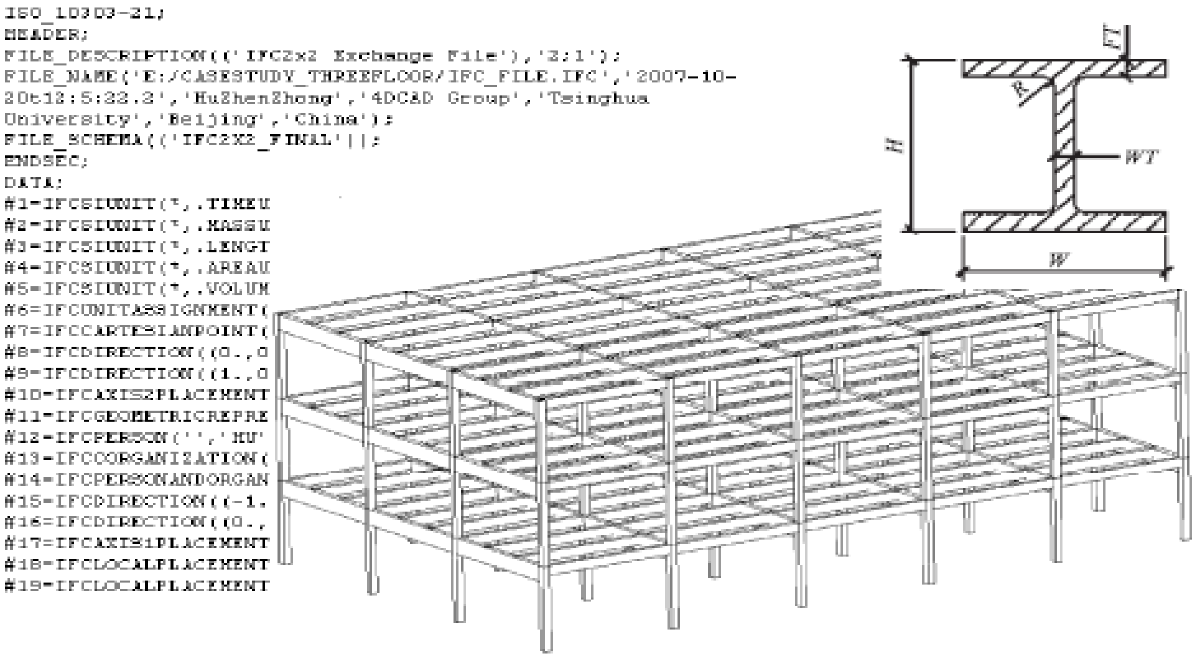


Abbildung 2-1: IFC description(left) and parametric 3D building model(right) [HU08]

2.2 Advantages and disadvantages of BIM

Advantages:

- Already highly recommended by lots of institutions, e.g. the European Commission
- Standardisation efforts already exist
- Avoidance of multiple entries
- Increase of security in terms of cost and deadline
- Increase of the efficiency of workflow
- Improvement of the productivity
- Optimisation of planning - and execution qualities
- Buildings, parts of a building, the static and building services can be controlled trade-spanning on collisions
- In contrast to the otherwise frequently used method of the critical path (Critical Path Method (CPM))[JAM59], BIM gives an overview of the resource components and the spatial context, which help identifying mistakes of the construction plan and remove the inconsistency of interpreting the project schedule

Disadvantages:

- Time-consuming 3/4-D model
- Data management and communication are needed when separating into several subject-specific working groups
- More communication and data exchange is necessary.
- There are difficulties to bring the separate models together.
- Rarely consequently used so far
- Advantages are difficult to realise, because people hold on to old methods
- Juristic question: Who is responsible for mistakes in the BIM-model?

Through this comparison it becomes clear, that although BIM offers many desirable advantages, the realization and adoption is difficult. If one of the participating teams refuses to use BIM, the detailed planning becomes absurd, because the work of this team cant be taken into account, e.g. when generating the work schedule with the BIM model. Additionally the responsibility is an obstacle to BIM as to every automated process.

3 Construction process simulation

Just like in many other branches of industry, e.g. the automotive industry, process simulations turned out to be very useful in the building industry as well. They can supportively be used to solve complex scheduling problems. However, those simulations are still expensive.
Data from different fields often have to be collected and updated manually. Because of that there are lots of efforts attempting to achieve that simulations can be built up at the basis of already existing information.
An appropriate BIM can facilitate the work significantly.

3.1 General information about the construction process

The basis in the building trade often is a 3D-building model. First of all, it has to be expanded by particular construction techniques.
It is important that the required components have to be modelled accordingly detailed. Furthermore, resource requirements and the calculated expense, which every company determines individually, have to be assigned to the separate process steps. Work sections may be divided and precedence constraints may be set.
Afterwards, construction processes can be tested for discrepancies with the help of visual analysis in a 4D-simulation. Thus, it can be adapted appropriately. Some of the required information are directly made available through the IFC-interface, e.g. the dimensions and quantities of the components [KOH10]. Other information still have to be added, e.g. groupings and precedence constraints. One way to enter the missing information interactively is to use the BIMSIM-Editor. Building methods are carried out with process patterns, which are unrelated to the project. The process patterns rule the sequence of the separate partial steps by predecessor-successor-relations. Those patterns can be used for every simulation of a database without further adaptations.
Paradigmatic for the simulations used nowadays is the so called "event-discrete simulation":
Start- and end dates of the separate construction processes, as well as the particular resource allocations are the result of the processing times, the sequence relationships and the available resources. By the use of an interactive time-scale, the construction process can be animated gradually. This also shows that the 4D-visualisation supports the analysis of the simulation results. It can be used as a useful tool for the improvement of the construction course simulation [KOH10].

3.2 Different types of models

Architectural model	Structural model
Defines spaces and appearances of building components	Defines a geometrical model for structure analysis
Belong to the same building object in the same 3D coordinate system	
Represent function, size, material behaviour, etc. of each component	
Can be converted into each other to a certain extend	
Appearance-attention focused	Geometrical and material information focused
Provides input information for the structural model	

Tabelle 3-1: Architectural versus structural model

Additionally, the structural model has two different representations. The *sophisticate analysis model* meshes 3D solid components and calculates stress and strain with the finite element method (FEM) and is more accurate.
The *simplified analysis model* breaks down 3D geometric components to 2D elements with profile parameters such as beam or shell elements, but in many cases this provides sufficient accuracy. [HU08]

To get from an architectural to a structural model you need to perfrom the following two transformation steps:

- Extract the geometrical data from IDC-desribed building objects

- Regenerate the structural model with structure analysis methods using structure analysis software like ANSYS and the embedded mesh functions for 3D solid elements

- This results in a sophisticated model, but there might exist difficulties in meshing irregular joints of building components.

- Consequently, a simplified model often is more attractive.

- Moreover, a way to identify joints of beam ad column or main beam and sub beam is needed.

Figure 3-2 shows one way of how to transform a architectural model and how to identify joints. Here, the nodes of each beam element are numbered and the algorithm searches for very close nodes, for example at the cross of beam and column (fig. 3-2 left), or nodes very close to the beam element, like at the cross of a column and a continuous beam (fig. 3-2 right), and then joins and renumbers them with the smaller number.

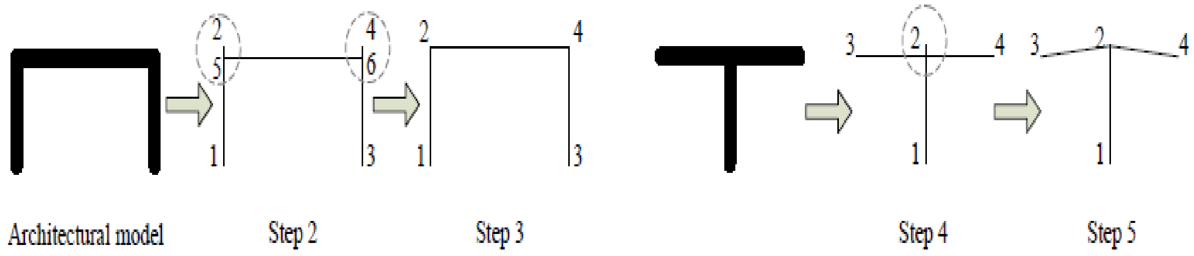


Abbildung 3-2: Identifying method for simplified analysis model from architectural model [HU08]

The resistance model is determined by the material properties such as density or mechanical and stress behaviour. As the resistance of the used building elements can vary, especially in event of RC, random factors are taken into account[HU08]:

$$R(t) = R(X_M, X_P, X_A, t) \quad \text{Gl. 3-1}$$

where $R(t)$ is the stochastic process function of resistance and X_M, X_P and X_A are random variables concerning material, geometry and calculation mode and t shows the time dependency.

The load distribution is also time dependent. In the two phases of setting up the supports and banding steel, safety inspection and structure analysis are often ignored, because the changing weight from the supports, workers and steel is very little compared to the building itself and the load spreads around the already completed slabs.

In the other two phases, which are pouring concrete and demolishing supports this is not the case. Pouring and vibrating concrete leads to large loads, which have to be taken into account. Also when removing the supports the new load distribution is not negligible. [HU08]

3.3 Constraint-based simulation and spatio-temporal restrictions

"[...]Many activities require exclusive access to certain spaces on construction site, which mostly depend on the construction progress. If these spatio-temporal dependencies are not adequately considered during construction scheduling, they may cause spatial conflicts on the construction site, resulting in incalculable delays and extra costs."[MAR10]

The region, in which those conflicts may occur, is divided into three time variant spatial areas:

Resource region	**construction region**	**Process region**
Used for labour resources like worker or building machines and consuming resources like constructing material	Used for the building itself, the construction site including storage area and the surroundings	Areas needed for certain process executions like a security zone, a save area or a post-processing area

Tabelle 3-3: Building site regions

Surrounding geometrical figures are used for the analysis of spatial dependencies. In case of the resource and construction region these are effectively bounding boxes according to the size of the respective component. For the process regions it is more complicated since they have to be associated with the process dynamically.
Figure 3-5 shows an example of generating such building boxes and how a time dependent conflict of two tower cranes can be shown up. The process region is a result of the position of the bounding boxes when moving from the starting point, defined by the position of the current pre-cast segment, and the mounting place. Additionally, these spatial restrictions have to be put into temporal context, because in may cases partial overlapping process regions are needed. So the power of the crane, the weight of the transported segment and its time needed for mounting needs to be considered to get the transport time. Together with the starting time from the work schedule and the spatial restrictions obtained from the bounding box scheme, the temporal spatial restrictions are defined.

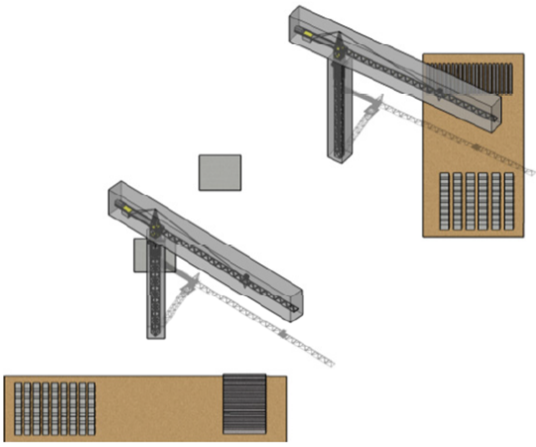
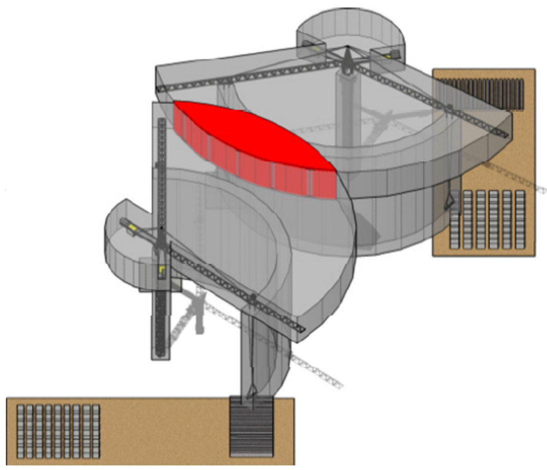


Abbildung 3-4: Example for bounding boxes



Construction region with spatio-temporal conflict

Abbildung 3-5: Bounding boxes and construction region with spatio-temporal conflict [MAR10]

In a constraint-based simulation, these spatial restrictions have to be considered additionally, so that they define the constraints together with the other necessary restrictions, such as technological sequence-relationships, required resources or available construction material.

This construction-based method enables the user to generate valid work schedules automatically. Bad work schemes are considered as those with a large spatial sensitivity, meaning that they result in long waiting times caused by many spatial conflicts. They can be optimized for example with the Monte-Carlo method, which varies all parallel executable processes and generates all possible valid work schemes. Evaluation criteria are the overall duration and the mentioned spatial sensitivity.
Figure 3-6 and figure 3-7 illustrate how much difference a good spatial sensitivity can make already for a very simple example like the two cranes with overlapping construction regions. In figure 3-6 there are many spatial conflicts, but by reordering the process steps for the second crane a conflict-less solution can be obtained. For this the technological sequence-relationships also has to be considered, so that not every desirable order is possible. [MAR10]

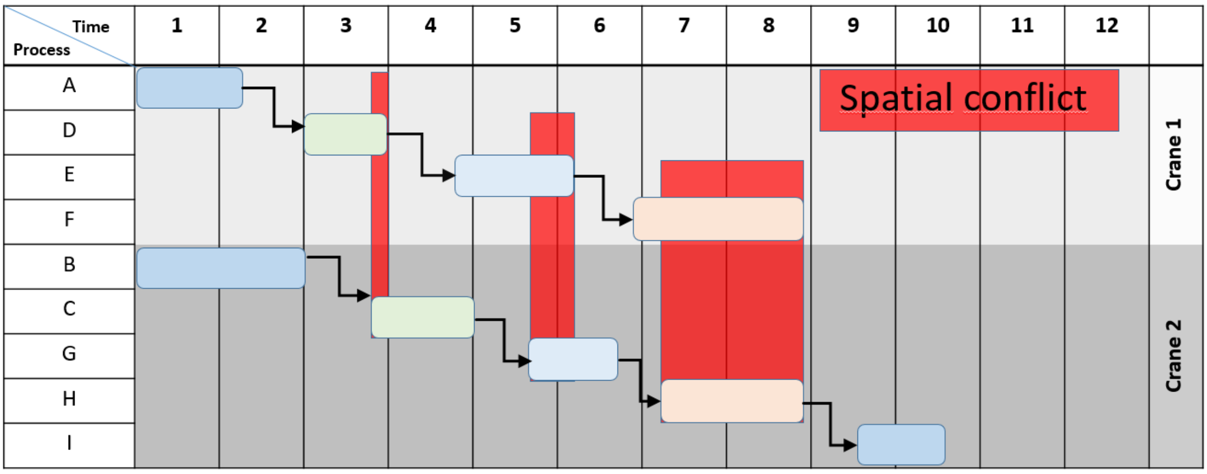


Abbildung 3-6: Not optimized work scheme taking account of technological and resource-based constraints adepted from [MAR10]

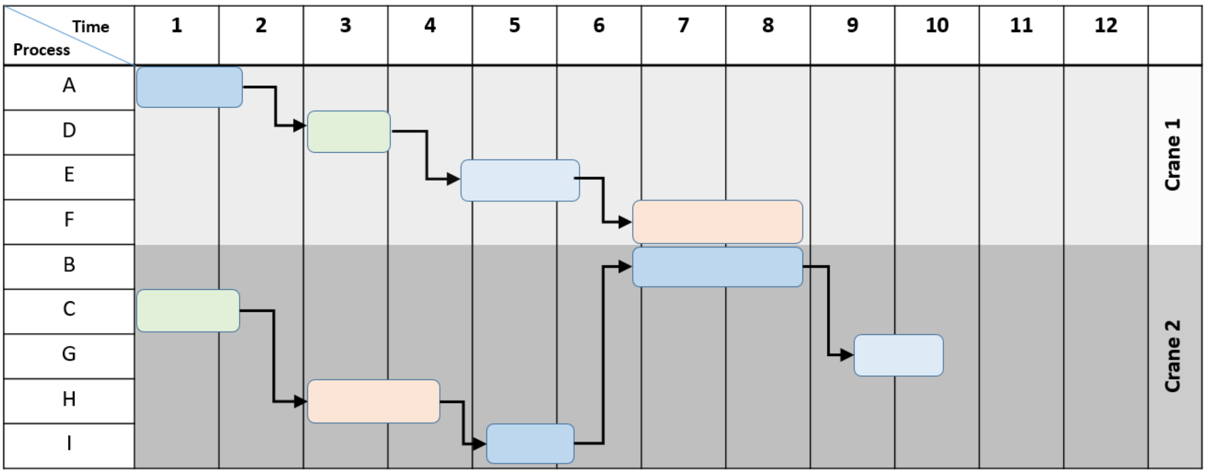


Abbildung 3-7: Monte-Carlo optimized work scheme taking account of technological and resource-based constraints adepted from [MAR10]

4 Outlook

To give a quick overview, this section shows up some of today's still developing models and IFC-based systems as well as some contrary statements .
"Up to now, quite a few professional systems based on IFC have been developed, e.g., a Design Information Management System (DIMS) in South Korea, an IFC model viewer supporting nD model application in England, and a collaborative design platform for architects and civil engineers in Singapore" [HU08].
Presently, structure analysis and safety analysis are mostly carried out by focusing on several time points during the construction process, rebuilding static structural models manually at each time point, and conducting probability-based calculations.
"However, not only the structure but the material behaviour and loading conditions are dynamically changed during construction process. This is why the structure during construction is also called 'time-dependent structure' " [HU08]. LIU Xila and WANG Jian presented a probability model and a dynamic model based on the theory of Bayes dynamic linear model (DLM) for estimation and analysis of the time-dependent structures. Nevertheless, because of immeasurable artificial intervention, this method was applied only to partial period and partial structure calculation [HU08]. This illustrates that there are restriction when using BIM, which have to be considered wisely until a solution is found.

Furthermore, there are people, who disagree to some of the proposals of BIM. An example is that software vendors and design consultants, who are using BIM, claim that it "enhances the quality of the construction documents by reducing human error as well as motivating architects to think through the building process for a more finalized project in the design phase" [LOV14]. People disagree to this statement, because they think it "is contrary to the findings of both widespread and established empirical research that has examined human error. Fundamentally, it is impossible to design technological systems to eliminate human errors" [LOV14]. This paper explains the theory of human errors and how the arise, which stands in contrast to the statement about BIM, which is given above. But it also suggest a systematic BIM implementation model to "reduce opportunities for human error" [LOV14].

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